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A SURVEY OF INTEGRATED OPTICS WITH BIBLIOGRAPHY

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16. ABSTRACT A brief survey of the field of integrated optics is made. Light coupling into films, modulation of light propagating in films, and current integrated optics developments and devices are discussed. It is concluded that one can expect integrated optics technology to revolutionize the electronics industry as completely as did microcircuit technology. An extensive bibliography for the field of integrated optics is included in this report.					
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A SURVEY OF INTEGRATED OPTICS WITH BIBLIOGRAPHY

INTRODUCTION

Throughout the nineteenth century, optics was a central subject of physics, commanding the attention of the greatest physicists of the time. However, the subject was seemingly closed by the brilliant work of a Scottish genius, J. C. Maxwell. Maxwell's equations withstood the twin revolutions of relativity and quantum theory and, coupled with the development of instruments that approached the theoretical optical limit, apparently exhausted the topic of theoretical and applied optics.

However, over the last two decades a deeper understanding of the limiting factors in many experiments and devices has been achieved. It has been found that experiments and projects throughout science are limited by fundamental optical problems of intensity, resolving power, stability, or photon statistics. The search for ways to overcome these problems has led to extensive efforts in applied optical physics. In addition, subtle interpretations of optical theory has brought advances in basic optical physics. These efforts expanded explosively with the advent of the laser.

One of the many promising applications of lasers is integrated optics, which involves a laser beam trapped in a thin film. The trapped beam is modulated or deflected by electrical or acoustical signals. Integrated optics is thus an attempt to apply thin-film technology to optical circuits and devices. In such devices it is now possible to construct literally thousands of gate and switching elements in optical paths of fractional millimeter length and to operate them simultaneously in parallel with beams of different wavelength from integrally constructed lasers. The possibilities for miniaturization of digital instrumentation through this approach are immense [1]. One can expect this approach to yield optical communication components with improved efficiency, ruggedness, and stability.

Integrated optical devices have the following advantages:

1. All the device elements are exposed and are easily accessible for measurement, probing, or modification.

2. Compared to microwaves, the optical wavelength is a factor of 10^4 smaller. Thus thin-film optical devices can be made very small and they can be placed next to each other on a single substrate, forming a system which is more compact, less vulnerable to environmental changes, and more economical.

3. Since the film thickness is comparable to the optical wavelength and since most of the light energy is confined within the film, the light intensity inside the film can be very large, even at a moderate laser power level. This is important in nonlinear interactions.

4. New possibilities in device design are provided by the fact that the phase-velocity of a light wave in a thin-film waveguide depends on the film thickness and the mode of propagation [2].

The concept of integrated optics was first formulated by Miller [3] in 1969. In the years since then, important advances have been made. The first of these is the great improvement made in the method of coupling a light wave propagating in free space into a well-defined mode of the thin-film guide. Three types of couplers are presently used: the prism-film coupler, the grating coupler, and the tapered film coupler. In some cases it is possible to get coupling efficiencies of almost 90 percent. The second major advance has been in the material used to make optical thin-film waveguides. The first films used showed large scattering losses (about 60 dB/cm), but materials developed more recently form films with losses on the order of 0.1 dB/cm. Other advances involve nonlinear and electro-optic effects observed in thin films and laser oscillation in iterated film structures [2].

Although the field of integrated optics (or thin-film optoelectronics) is still in a very elementary stage, it appears to have many potential uses. It is an interdisciplinary science, involving physical optics, materials, film fabrication, and electronics. In this report the author briefly surveys the field, discussing light coupling into films, modulation of light in films, and current developments and devices. An extensive bibliography with articles listed by subgroups and in chronological order is included.

OPTICAL COUPLERS

Since integrated optics by definition involves thin-film optical devices, the first problem faced by workers in the field was the problem of finding

methods to couple a light wave propagating in free space into a well-defined mode of the thin-film guide. Early efforts included focusing of light onto the edge of a pn junction [4 - 7] and direct edge illumination of films [8 - 9]. These methods were handicapped by excessive edge scattering and simultaneous excitation of many modes. At present three couplers are in use: the prism-film coupler, the optical grating coupler, and the tapered-film coupler. Each of them is discussed in the following paragraphs.

The Prism-Film Coupler

The prism-film coupler was developed by Tien et al. in 1969 [10]. It is essentially a modification of the well-known frustrated total reflection interference filter which has been in existence since 1947 [11]. A diagram of this coupler may be seen in Figures 1 and 2. It consists of a prism with refractive index n_3 sitting on top of a film with refractive index n_2 and a substrate with refractive index n_1 . There is an air gap between the prism and the film. Since the film is to act as an optical waveguide, n_2 must be greater than n_1 (and also greater than one, the refractive index of air). This follows from Snell's Law. It should also be noted that in order to excite all possible waveguide modes in the film, the refractive index of the prism should be greater than that of the film. At this point it should be trivially obvious that the prism and the film must be as transparent and as nonscattering as possible to the light being utilized.

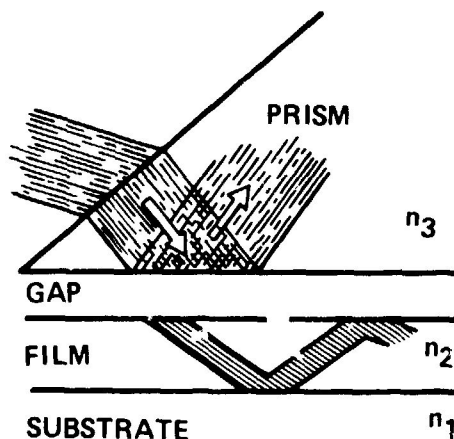


Figure 1. Prism-film coupler.

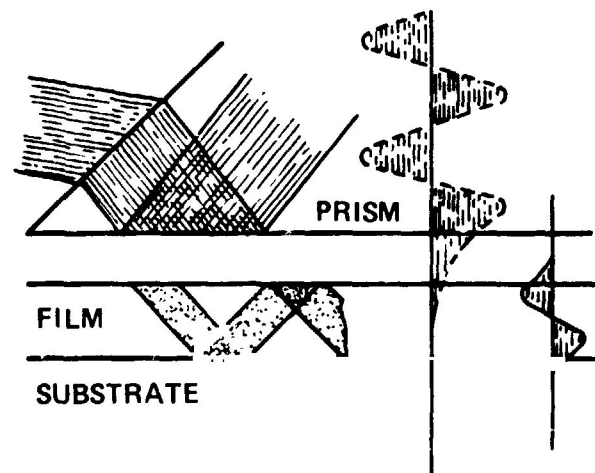


Figure 2. Prism-film coupler and evanescent field distributions.

To activate the coupler, an incoming laser beam is fed into the prism and is totally reflected at the prism base. Because of the total reflection, the field in the prism is a standing wave that extends into an exponentially decreasing field below the prism base. This rapidly decaying part of the field does not represent a free radiation. It is called the evanescent field (Fig. 2), and it is commonly observed in the walls of microwave guides and cavities. At this point nothing much is happening. However, if the air gap between prism and film is made very small (on the order of $1/8$ to $1/4$ of the vacuum optical wavelength), the evanescent field below the prism then penetrates into the film and excites a light wave in the film. This coupling process is the so-called "optical tunneling" mentioned in the literature. If the horizontal component of the wave vector of one of the waveguide modes is equal to that of the incoming light wave in the prism, the light wave in the prism is coupled exclusively to this waveguide mode and the laser beam is said to be in a synchronous direction. It is therefore possible to couple the light wave to any waveguide mode simply by choosing a proper angle of incidence for the incoming laser. Input coupling efficiencies of 88 percent have been reported [12].

Note that the coupling process is reversible. It is therefore necessary to have the totally reflected beam strike as closely as possible to the edge of the prism base. This prevents the light from being coupled out of the waveguide and back into the prism. Of course, to couple light back out of the waveguide one merely takes another prism and places it similarly to the input prism at the desired exit point along the beam path. The prism-film coupler is a perfect output coupler and will couple out all the light energy in the film.

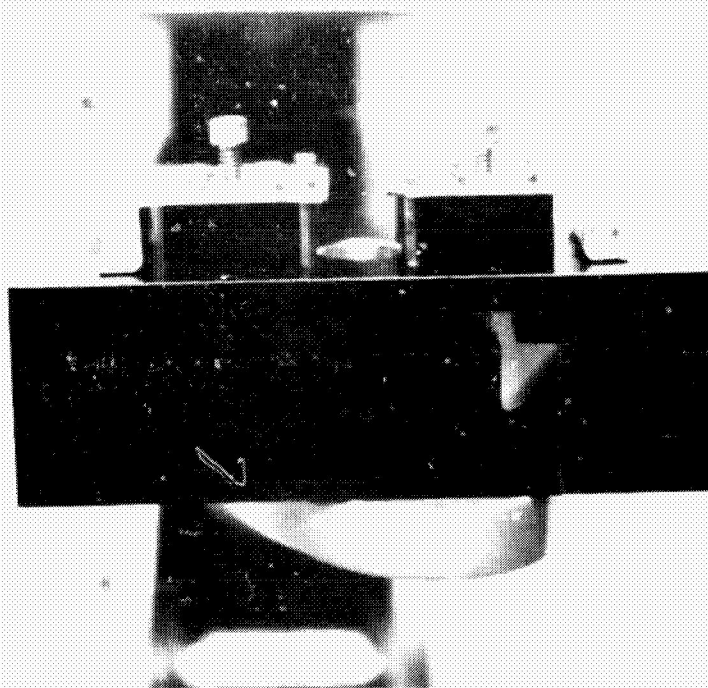
For more efficient input coupling, knife edges can be pressed against the back of the substrate, thus causing a closer approximation of the ideal coupling configuration. Such knife edges can be observed in the photograph of the prism-film coupler developed at Marshall Space Flight Center (MSFC) (Fig. 3).

It may be noted that by correlating the measured values of the synchronous directions with a theoretical calculation of the waveguide modes it is possible to independently determine the film thickness and refractive index. An accuracy within 1 part in 1000 for the refractive index and 1 percent for the thickness has been achieved [13].

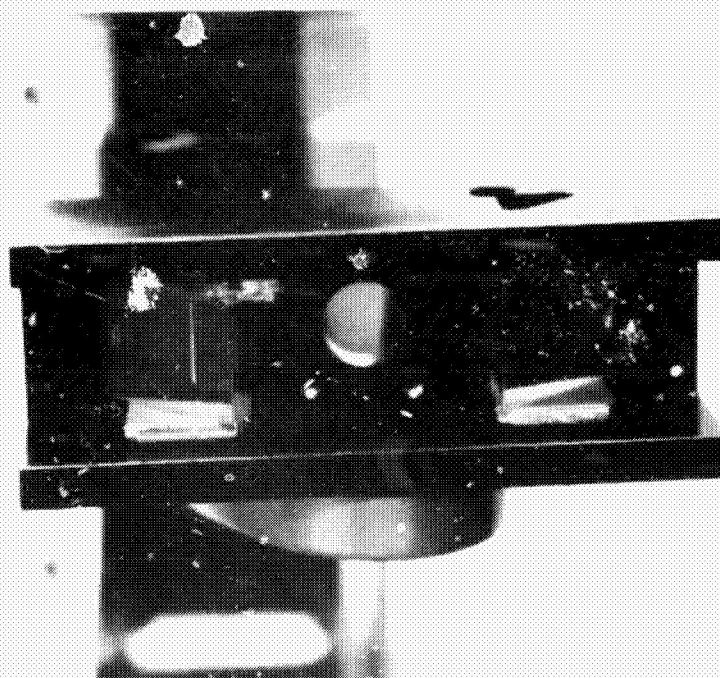
The Optical Grating Coupler

The optical grating coupler [14 and 15] is a phase grating made of photoresist or dichromated gelatin. Such a grating can be fabricated by

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a. Top view.



b. Side view.

Figure 3. MSFC-developed prism-film coupler.

holographic techniques on top of or (in the case of photoresist waveguides) in a thin film. A laser beam incident on the phase grating is modulated such that when it encounters the waveguide surface it contains many Fourier components. If one of these components matches the wave motion of one of the waveguide modes of the film, the light beam is coupled to that mode and is fed into the film. This coupling is thus a function of the beam's initial angle of incidence.

Such gratings have been made at MSFC in the holographic facilities. The gratings were formed from Kodak Micro-Neg Photoresist which had been exposed to a 456-nm laser interferometer fringe pattern and developed. The laser was a Spectra Physics Model 165 Argon laser operated at full power (about 0.1 watt at that wavelength). The two beams forming the interferometer fringe pattern were incident on the photoresist film at angles of 30 deg from the film normal. The photoresist films were formed by standard spin techniques. Diffraction efficiencies in these gratings were relatively high as it was possible to observe up to the third order of diffraction with them. The gratings were successfully used to couple with ZnS and clarified Kodak KPR photoresist thin-film waveguides [16].

The Tapered-Film Coupler

The tapered-film coupler [17] is simply a thin-film waveguide deposited on a substrate in such a manner that one film edge tapers off to nothing (Fig. 4). Its method of operation can be best understood by consideration of ray optics (Fig. 5). A light beam with the proper angle of incidence will pass into the film and be reflected off the tapered edge in such a way as to exceed the waveguide's critical angle on later reflections. The beam will thus be trapped. As with all optical waveguides it is required that the waveguide refractive index be greater than the substrate refractive index.

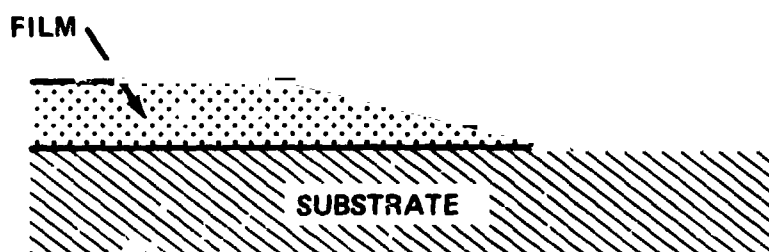


Figure 4. Tapered-film coupler.

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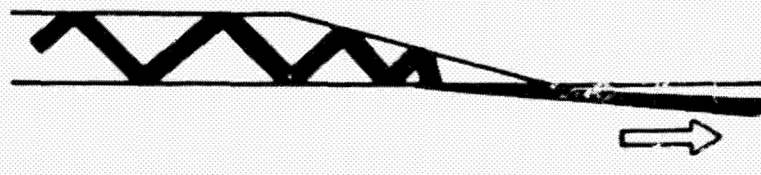


Figure 5. Tapered-film coupler with coupled light path.

Tapered-film couplers have been made at MSFC by vacuum deposition of ZnS onto a substrate that had a sharp blade taped to its surface. (Standard microscope slides were used as substrates.) A tapered film-edge was formed in the gap between the blade and the substrate. This coupler can be seen in operation in Figure 6.

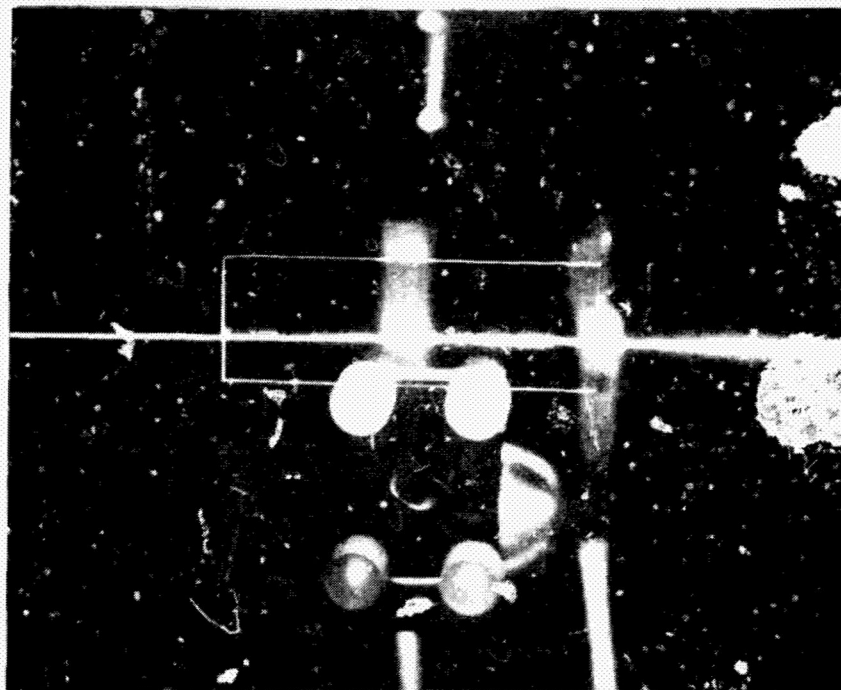


Figure 6. MSFC-developed tapered-film coupler in operation.

LIGHT MODULATION

The modulation of a light beam which is traveling in a thin-film waveguide is discussed in this section. There are various ways of modulating

such a beam. Acoustical, electrical, magnetic, physical (obtained by varying the physical properties of the waveguide), and substrate (obtained by acting on the substrate) modulations are examined here.

Acoustical Modulation

It is apparent that active acousto-optic components will find application in integrated optics circuits. Such devices as beam deflectors, switches, and spectral and amplitude modulators may be built using acousto-optics. It should be noted that surface guided acoustic waves and optical guided waves have many properties in common. This similarity between the two types of waves enables the effective use of both in integrated optics. For example, both types of guided waves have most of their energy concentrated in the waveguide vicinity, both may be guided simultaneously by the appropriate waveguide structures, and both are dispersive with higher-order modes exhibiting cutoff behavior.

The usefulness of the acousto-optic interaction in the construction of beam deflectors, switches and modulators has been demonstrated by Kuhn et al. [18 and 19], who demonstrated both Bragg deflection and mode conversion of optical guided waves by means of surface acoustic waves. This modulator can be seen in Figure 7. Another potential use of the acousto-optic interaction was suggested by Chang [20], who proposed extending the grating coupler concept by having the periodic structure required for coupling caused by the periodic index change arising from a surface acoustic wave. By varying the acoustic wavelength one could then scan the output electrically.

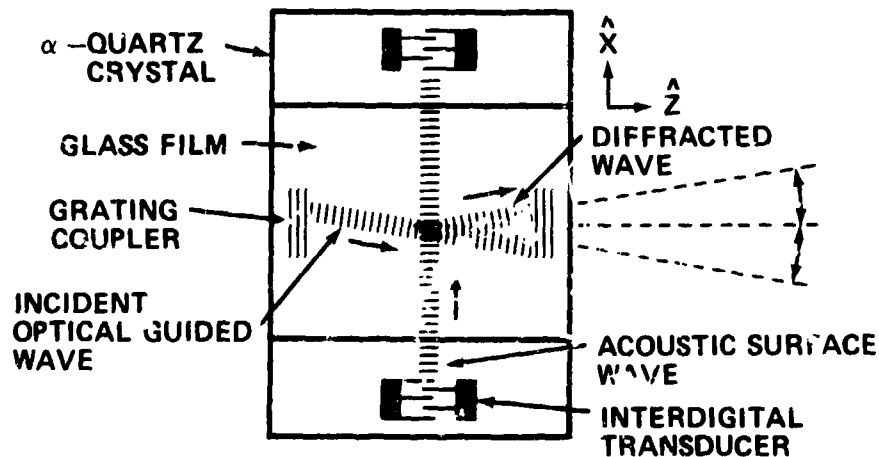


Figure 7. The acousto-optic modulator of Kuhn et al.

Electrical Modulation

Active electro-optical devices could perform the same functions as acousto-optical devices, that is, they could function as beam deflectors, switches, and spectral and amplitude modulators. Other devices are, of course, also possible.

An interdigital electro-optic thin-film modulator has been developed by Polky et al. [21]. The device uses nitrobenzene as the active waveguide material and obtains amplitude modulation of an optical guided mode by Bragg diffraction from periodic index variations in the guiding layer. A modulation efficiency of 50 percent was obtained. To construct the device, interdigital copper electrodes 1 micron thick were evaporated onto a standard microscope slide ($n = 1.52$). Spacers of NaF were evaporated onto both ends to support an input-output prism. Modulation of a mechanically chopped light beam was applied by putting a 200-V, 8000-Hz signal across the interdigital electrodes. This modulator can be seen in Figure 8.

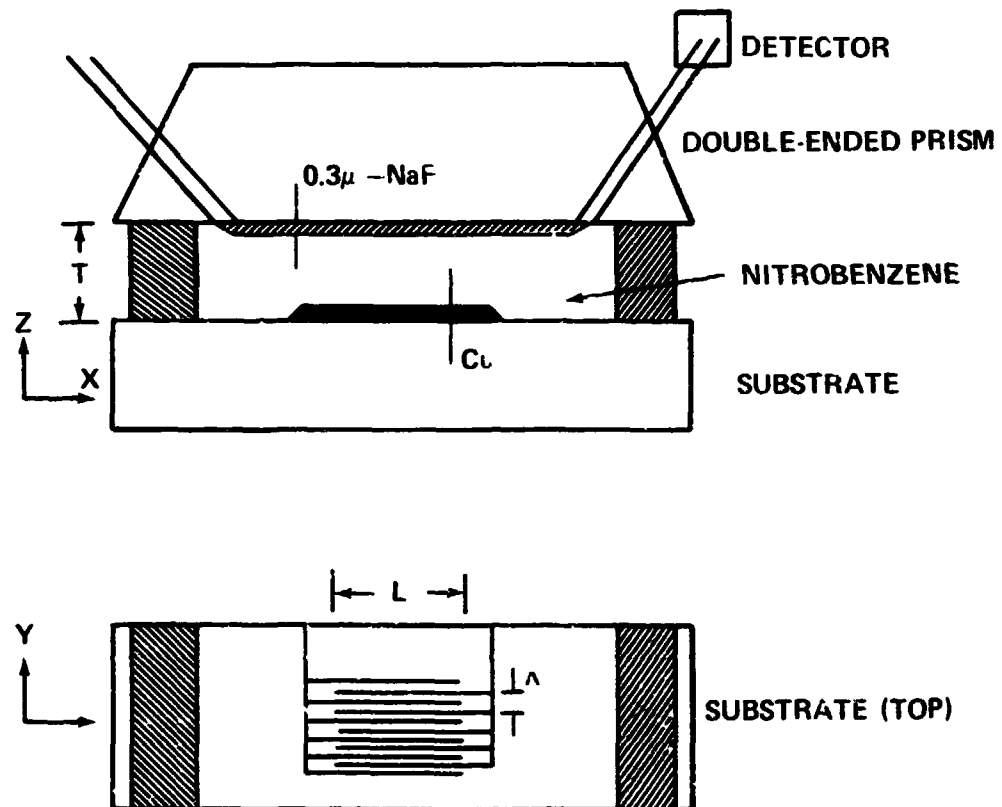


Figure 8. Interdigital electro-optic thin-film modulator [21].

Magnetic Modulation

A magneto-optic thin-film device developed by Tien et al. [22] (Fig. 9) is capable of switching or modulating light beams. The device utilizes a single-crystal scandium-substituted yttrium iron garnet film heteroepitaxially grown on a single-crystal garnet substrate. The film is of a type originally developed for use in magnetic bubble devices [23]. A serpentine electric circuit fabricated by photolithographic techniques is used to produce an RF magnetic field for modulation. Light propagating in the TM (or TE) waveguide mode can then be converted by the magneto-optic effect (Faraday rotation) into the TE (or TM) waveguide mode. By combining an external dc magnetic field with the RF field, it is possible to modulate the output intensity of the two modes according to the current in the circuit. By use of a birefringent output prism it is then possible to switch the beam from one output path to the other. The current device utilizes light from a 1152 nm laser.

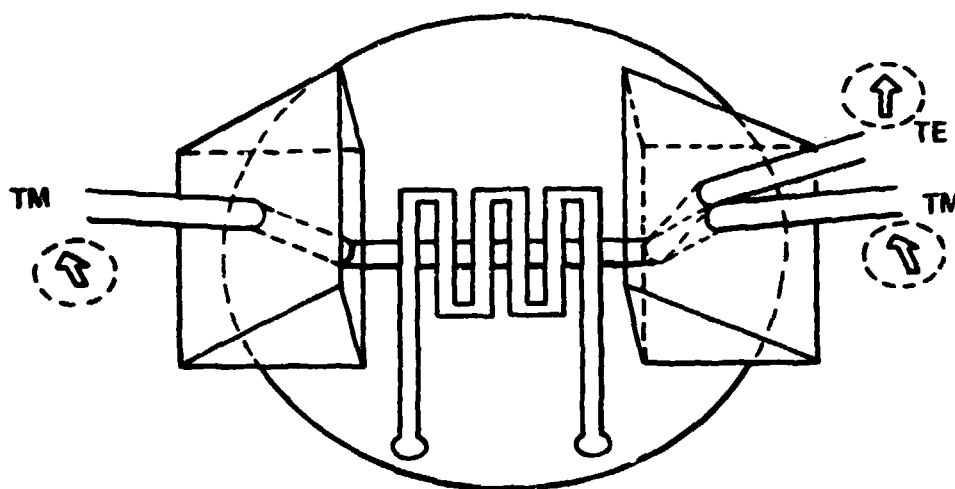


Figure 9. Magneto-optic switch or modulator [22].

Physical Modulation

It is possible to passively guide light by constructing a film with varying physical properties. For example, one can make thin-film prisms and lenses by suitably shaping the boundary lines between regions of thin and thick film thickness [24]. Other techniques can be used. Shubert et al. have suggested shaped structures of different refractive indices either inserted in

the waveguide [9] or deposited on top of the main waveguide [25]. Righini et al. [26] constructed a thin film geodesic lens by covering a spherical glass substrate with a thin epoxy film which acted as the waveguide.

Substrate Modulation

In structures such as those considered here, the properties of the substrate may be used to control the propagation of light in the film. Since it is difficult to control the optical properties of a thin film, the substrate becomes an attractive medium for optical control functions. Wave propagation in optical waveguides on substrates of magnetic, optically active, or birefringent material have been analyzed by Wang et al. [27]. They have shown that TE \rightleftharpoons TM mode conversion is possible by using an anisotropic material as the substrate and have outlined the characteristics of such a mode converter. A preliminary device which achieves approximately 50 percent mode conversion has been constructed. Once mode conversion is achieved, devices like the gyrator, isolator, and optical readout are possible using this approach. By externally controlling the dielectric properties of the substrate via electro-optic and magneto-optic effects, modulators and optical switches could be built [27].

SUMMARY

The field of integrated optics has been briefly surveyed. Light coupling into films, modulation of light propagating in films, and current integrated optics developments and devices have been discussed. It appears that one can expect integrated optics technology to revolutionize the electronics industry as completely as did microcircuit technology. An extensive bibliography for the field of integrated optics constitutes the remainder of this report.

BIBLIOGRAPHY

General

1. Miller, S. E.: Integrated Optics: An Introduction. Bell System Tech. J., vol. 48, 1968, p. 2059.
2. Goell, J. E. and Standley, R. D.: Integrated Optical Circuits. IEEE Proc., vol. 58, 1970, p. 1504.
3. Ulrich, R. and Martin, R. J.: Geometrical Optics in Thin Film Light Guides. Appl. Opt., vol. 10, 1971, p. 2077.
4. Tien, P. K.: Light Waves in Thin Films and Integrated Optics. Appl. Opt., vol. 10, 1971, p. 2395.
5. Kapany, N. S. and Burke, J. J.: Optical Waveguides. Academic Press, New York, 1972.
6. Miller, S. E.: A Survey of Integrated Optics. IEEE J. Quan. Elec., vol. QE-8, 1972, p. 199.
7. Pole, R. V.; Miller, S. E.; Harris, J. H.; and Tien, P. K.: Integrated Optics and Guided Waves - A Report of the Topical Meeting. Appl. Opt., vol. 11, 1972, p. 1675.
8. Hill, K. O.; Watanabe, A.; and Chambers, J. G.: Evanescent-Wave Interactions in an Optical Wave-Guiding Structure. Appl. Opt., vol. 11, 1972, p. 1952.
9. Garvin, H. L.; Garmire, E.; Somekh, S.; Stoll, H.; and Yariv, A.: Ion Beam Micromachining of Integrated Optics Components. Appl. Opt., vol. 12, 1973, p. 455.
10. Tien, P. K.: Abstract: Single-Crystal Films and Development of Active Integrated Optics. J. Vac. Sci. Technol., vol. 10, 1973, p. 289.

Optical Couplers

1. Leurgans, P. and Turner, A. F.: Frustrated Total Reflection Interference Filters. *J. Opt. Soc. Am.*, vol. 37, 1947, p. 983.
2. Iogansen, L. V.: Theory of Resonant Electromagnetic Systems That Use Total Internal Reflection. *Sov. Phys.-Tech. Phys.*, vol. 7, 1962, p. 295.
3. Iogansen, L. V.: Theory of Resonant Electromagnetic Systems With Total Internal Reflection II. *Sov. Phys.-Tech. Phys.*, vol. 8, 1964, p. 985.
4. Osterberg, H. and Smith, L. W.: Transmission of Optical Energy Along Surfaces: Part II, Inhomogeneous Media. *J. Opt. Soc. Am.*, vol. 54, 1964, p. 1078.
5. Iogansen, L. V.: Theory of Resonant Electromagnetic Systems With Total Internal Reflection III. *Sov. Phys.-Tech. Phys.*, vol. 11, 1967, p. 1529.
6. Lotsch, H. K. V.: Reflection and Refraction of a Beam of Light at a Plane Interface. *J. Opt. Soc. Am.*, vol. 58, 1968, p. 551.
7. Tien, P. K.; Ulrich, R.; and Martin, R. J.: Modes of Propagating Light Waves in Thin Deposited Semiconductor Films. *Appl. Phys. Letters*, vol. 14, 1969, p. 291.
8. Midwinter, J. E. and Zernike, F.: Experimental Studies of Evanescent Wave Coupling into a Thin-Film Waveguide. *Appl. Phys. Letters*, vol. 16, 1970, p. 198.
9. Dakss, M. L.; Kuhn, L.; Heidrich, P. F.; and Scott, B. A.: Grating Coupler for Efficient Excitation of Optical Guided Waves in Thin Films. *Appl. Phys. Letters*, vol. 16, 1970, p. 523.
10. Harris, J. H.; Shubert, R.; and Polky, J. N.: Beam Coupling to Films. *J. Opt. Soc. Am.*, vol. 60, 1970, p. 1007.
11. Kogelnik, H. and Sosnowski, T. P.: Holographic Thin Film Couplers. *Bell System Tech. J.*, vol. 49, 1970, p. 1602.

12. Midwinter, J. E.: Evanescent Field Coupling into a Thin-Film Waveguide. IEEE J. Quan. Elec., vol. QE-6, 1970, p. 583.
13. Ulrich, R.: Theory of the Prism-Film Coupler by Plane-Wave Analysis. J. Opt. Soc. Am., vol. 60, 1970, p. 1337.
14. Tien, P. K. and Ulrich, R.: Theory of Prism-Film Light Guides. J. Opt. Soc. Am., vol. 60, 1970, p. 1325.
15. Harris, J. H. and Shubert, R.: Variable Tunneling Excitation of Optical Surface Waves. IEEE Trans. Micro. Theor. Tech., vol. MTT-19, 1971, p. 269.
16. Tien, P. K. and Martin, R. J.: Experiments on Light Waves in a Thin Tapered Film and a New Light-Wave Coupler. Appl. Phys. Letters, vol. 18, 1971, p. 398.
17. Midwinter, J. E.: Theory of an Ultra-Broad-Band Optical Dielectric Waveguide Coupler System. IEEE J. Quan. Elec., vol. QE-7, 1971, p. 345.
18. Tamir, T. and Bertoni, H. L.: Lateral Displacement of Optical Beams at Multilayered and Periodic Structures. J. Opt. Soc. Am., vol. 61, 1971, p. 1397.
19. Ulrich, R.: Optimum Excitation of Optical Surface Waves. J. Opt. Soc. Am., vol. 61, 1971, p. 1467.
20. Hope, L. L.: Theory of Optical Grating Couplers. Opt. Comm., vol. 5, 1972, p. 179.
21. Harris, J. H.; Winn, R. K.; and Dalgoutte, D. G.: Theory and Design of Periodic Couplers. Appl. Opt., vol. 11, 1972, p. 2234.
22. Sohler, W.: Light-Wave Coupling to Optical Waveguides by a Tapered Cladding Medium. J. Appl. Phys., vol. 44, 1973, p. 2343.
23. Bell, R. J.; Fischer, B.; and Tyler, L. L.: Coupling to Surface Waves with Prisms via Attenuated Total Reflection. Appl. Opt., vol. 12, 1973, p. 832.
24. Ogawa, K. and Chang, W. S. C.: Analysis of Holographic Thin Film Grating Coupler. Appl. Opt., vol. 12, 1973, p. 2167.

Optical Modulation

1. Nelson, D. F. and Reinhart, F. K.: Light Modulation by the Electro-Optic Effect in Reverse-Biased GaP P-N Junctions. Appl. Phys. Letters, vol. 5, 1964, p. 148.
2. Klein, W. R.; Cook, B. D.; and Mayer, W. G.: Light Diffraction by Ultrasonic Gratings. Acustica, vol. 15, 1965, p. 67.
3. Pershan, P. S.: Magneto-Optical Effects. J. Appl. Phys., vol. 38, 1967, p. 1482.
4. Foster, N. F.; Coquin, G. A.; Rozgonyi, G. A.; and Vannatta, F.A.: Cadmium Sulphide and Zinc Oxide Thin-Film Transducers. IEEE Trans. Son. Ultrason., vol. SU-15, 1968, p. 28.
5. Suematsu, Y.: Tunable Parametric Oscillator Using a Guided Wave Structure. Japan J. Appl. Phys., vol. 9, 1970, p. 798.
6. Hall, D.; Yariv, A.; and Garmire, E.: Observation of Propagation Cutoff and its Control in Thin Optical Waveguides. Appl. Phys. Letters, vol. 17, 1970, p. 127.
7. Kuhn, L.; Dakss, M. L.; Heidrich, P. F.; and Scott, B. A.: Deflection of an Optical Guided Wave by a Surface Acoustic Wave. Appl. Phys. Letters, vol. 17, 1970, p. 265.
8. Chang, W. S. C.: Acousto-Optical Deflections in Thin Films. IEEE J. Quan. Elec., vol. QE-7, 1971, p. 167.
9. Telesnin, R. V.; Nestrelay, T. I.; Koshkin, L. I.; Shishkov, A. G.; Ekonomov, N. A.; and Antonov, L. I.: Study of Magnetization of Single Crystal Ferrite Films by Magneto-Optical Faraday Effect. Phys. Stat. Sol., vol. 4, 1971, p. 805.
10. Wand, S.; Crow, J. D.; and Shah, M. L.: Studies of Magneto-optic Effects for Thin-Film Optical-Waveguide Applications. IEEE Trans. Mag., vol. 7, 1971, p. 385.

11. Channin, D. J.: Voltage-Induced Optical Waveguide. Appl. Phys. Letters, vol. 19, 1971, p. 128.
12. Wang, S.; Crow, J. D.; and Shah, M.: Thin-Film Optical-Waveguide Mode Converters Using Gyrotropic and Anisotropic Substrates. Appl. Phys. Letters, vol. 19, 1971, p. 187.
13. Kuhn, L.; Heidrich, P. F.; and Lean, E. G.: Optical Guided Wave Mode Conversion by Acoustic Surface Wave. Appl. Phys. Letters, vol. 19, 1971, p. 428.
14. Andrews, R. A.: Crystal Symmetry Effects on Nonlinear Optical Processes in Optical Waveguides. IEEE J. Quan. Elec., vol. QE-7, 1971, p. 523.
15. Harris, J. H. and Russo, D. P. G.: Electro-Optic Modulation in a Thin Film Waveguide. Appl. Opt., vol. 10, 1971, p. 2786.
16. Wang, S.; Shah, M. L.; and Crow, J. D.: Wave Propagation in Thin-Film Optical Waveguides Using Gyrotropic and Anisotropic Materials as Substrates. IEEE J. Quan. Elec., vol. QF-8, 1972, p. 212.
17. Polky, J. N. and Harris, J. H.: Interdigital Electro-Optic Thin-Film Modulator. Appl. Phys. Letters, vol. 21, 1972, p. 307.
18. Tien, P. K.; Martin, R. J.; Wolfe, R.; LeCraw, R. C.; and Blank, S. L.: Switching and Modulation of Light in Magneto-Optic Waveguides of Garnet Films. Appl. Phys. Letters, vol. 21, 1972, p. 394.
19. Kino, G. S. and Shaw, J.: Acoustic Surface Waves. Sci. Am., vol. 227, 1972, p. 51.
20. de Klerk, J.: Elastic Surface Waves. Phys. Today, vol. 25, 1972, p. 32.
21. Bierbaum, P.: Interaction of Ultrasonic Surface Waves with Conduction Electrons in Thin Metal Films. Appl. Phys. Letters, vol. 21, 1972, p. 595.
22. Somekh, S.; Garmire, E.; Yariv, A.; Garvin, H. L.; and Hunsperger, R. G.: Channel Optical Waveguide Directional Couplers. Appl. Phys. Letters, vol. 22, 1973, p. 46.

23. Wu, S. Y.; Takei, W. J.; and Francombe, M. H.: Electro-Optic Contrast Observations in Single-Domain Epitaxial Films of Bismuth Titanate. *Appl. Phys. Letters*, vol. 22, 1973, p. 26.
24. Giallorenzi, T. G.: Acousto-Optical Deflection in Thin-Film Waveguides. *J. Appl. Phys.*, vol. 44, 1973, p. 242.
25. Dabby, F. W.; Saifi, M. A.; and Kestenbaum, A.: High-Frequency Cutoff Periodic Dielectric Waveguides. *Appl. Phys. Letters*, vol. 22, 1973, p. 190.
26. Burns, W. K. and Andrews, R. A.: "Noncritical" Phase Matching in Optical Waveguides. *Appl. Phys. Letters*, vol. 22, 1973, p. 143.
27. Cheo, P. K.: Pulse Amplitude Modulation of a CO₂ Laser in an Electro-Optic Thin-Film Waveguide. *Appl. Phys. Letters*, vol. 22, 1973, p. 241.
28. Stolen, R. H. and Ashkin, A.: Optical Kerr Effect in Glass Waveguide. *Appl. Phys. Letters*, vol. 22, 1973, p. 294.
29. Wemple, S. H.; Dillon, J. F., Jr.; Van Uitert, L. G.; and Grodkiewicz W. H.: Iron Garnet Crystals for Magneto-Optic Light Modulators at 1.064 μm . *Appl. Phys. Letters*, vol. 22, 1973, p. 331.
30. Kino, G. S. and Wagers, R. S.: Theory of Interdigital Couplers on Nonpiezoelectric Substrates. *J. Appl. Phys.*, vol. 44, 1973, p. 1480.
31. Taylor, H. F.: Optical Switching and Modulation in Parallel Dielectric Waveguides. *J. Appl. Phys.*, vol. 44, 1973, p. 3257.
32. Brandt, G. B.; Gottlieb, M.; and Conroy, J. J.: Bulk Acoustic Wave Interaction with Guided Optical Waves. *Appl. Phys. Letters*, vol. 23, 1973, p. 53.
33. Shah, M. L.: Fast Acousto-Optical Waveguide Modulators. *Appl. Phys. Letters*, vol. 23, 1973, p. 75.
34. Suematsu, Y.; Sasaki, Y.; and Shibata, K.: Second-Harmonic Generation Due to a Guided Wave Structure Consisting of Quartz Coated With a Glass Film. *Appl. Phys. Letters*, vol. 23, 1973, p. 137.

35. Hammer, J. M.; Channin, D. J.; and Duffy, M. T.: Fast Electro-optic Waveguide Deflector Modulator. Appl. Phys. Letters, vol. 23, 1973, p. 176.
36. Martin, W. E.: Waveguide Electro-Optic Modulation in II - VI Compounds. J. Appl. Phys., vol. 44, 1973, p. 3703.

Optical Focusing

1. Shubert, R. and Harris, J. H.: Optical Guided-Wave Focusing and Diffraction. J. Opt. Soc. Am., vol. 61, 1971, p. 154.
2. Righini, G. C.; Russo, V.; Sattini, S.; and de Francia, G. T.: Thin Film Geodesic Lens. Appl. Opt., vol. 11, 1972, p. 1442.
3. Righini, G. C.; Russo, V.; Sottini, S.; and di Francia, G. T.: Geodesic Lenses for Guided Optical Waves. Appl. Opt., vol. 12, 1973, p. 1477.
4. Suematsu, Y.; Furuya, K.; and Kambayashi, T.: Focusing Properties of Thin-Film Lenslike Light Guide for Integrated Optics. Appl. Phys. Letters, vol. 23, 1973, p. 78.

Optical Materials

1. Reinhart, F. K.: Reverse-Biased Gallium Phosphide Diodes as High-Frequency Light Modulators. J. Appl. Phys., vol. 39, 1968, p. 3426.
2. Schineller, E. R.; Flam, R. P.; and Wilmot, D. W.: Optical Waveguides Formed by Proton Irradiation of Fused Silica. J. Opt. Soc. Am., vol. 58, 1968, p. 1171.
3. Reinhart, F. K.; Nelson, D. F.; and McKenna, J.: Electro-Optic and Waveguide Properties of Reverse-Biased Gallium Phosphide p-n Junctions. Phys. Rev., vol. 117, 1969, p. 1208.
4. Schmidt, P. F.; Rand, M. J.; Mitchell, J. P.; and Ashner, J. D.: Radiation-Insensitive Silicon Oxynitride Films for Use in Silicon Devices. IEEE Trans. Nucl. Sci., vol. NS-16, 1969, p. 211.

5. Pearson, A. D.; French, W. G.; and Rawson, E. G.: Preparation of a Light Focusing Glass Rod by Ion-Exchange Techniques. Appl. Phys. Letters, vol. 15, 1969, p. 76.
6. French, W. G. and Pearson, A. D.: Refractive Index Changes Produced in Glass by Ion Exchange. Cer. Bull., vol. 49, 1970, p. 974.
7. Hensler, D. H.; Cuthbert, J. D.; Martin, R. J.; and Tien, P. K.: Optical Propagation in Sheet and Pattern Generated Films of Ta₂O₅. Appl. Opt., vol. 10, 1971, p. 1037.
8. Ostrowsky, D. B. and Jacques, A.: Formation of Optical Waveguides in Photoresist Films. Appl. Phys. Letters, vol. 18, 1971, p. 556.
9. Chang, W. S. C. and Loh, K. W.: Experimental Observation of 10.6- μ m Guided Waves in Ge Thin Films. Appl. Opt., vol. 10, 1971, p. 2361.
10. Wu, S. Y.; Takei, W. J.; and Francombe, M. H.: Domain Structure and Polarization Reversal in Films of Ferroelectric Bismuth Titanate. Ferroelectrics, vol. 3, 1972, p. 217.
11. Weber, H. W.; Ulrich, R.; Chandross, E. A.; and Tomlinson, W. J.: Light-Guiding Structures of Photoresist Films. Appl. Phys. Letters, vol. 20, 1972, p. 143.
12. Ulrich, R. and Weber, H. P.: Solution-Deposited Thin Films as Passive and Active Light-Guides. Appl. Opt., vol. 11, 1972, p. 428.
13. Ulrich, R.; Weber, H. P.; Chandross, R. A.; Tomlinson, W. J.; and Franke, E. A.: Embossed Optical Waveguides. Appl. Phys. Letters, vol. 20, 1972, p. 213.
14. Tien, P. K.; Smolinsky, G.; and Martin, R. J.: Thin Organosilicon Films for Integrated Optics. Appl. Opt., vol. 11, 1972, p. 637.
15. Standley, R. D.; Gibson, W. M.; and Rodgers, J. W.: Properties of Ion-Bombarded Fused Quartz for Integrated Optics. Appl. Opt., vol. 11, 1972, p. 1313.
16. Schineller, E. R.: Comment on: Experimental Observation of 10.6- μ m Guided Waves in Ge Thin Films. Appl. Opt., vol. 11, 1972, p. 1654.

17. Chang, W. S. C. and Loh, K. W.: Authors Reply to Comments on: Experimental Observation of 10.6- μ m Guided Waves in Ge Thin Films. Appl. Opt., vol. 11, 1972, p. 1655.
18. Goell, J. E.; Standley, R. D.; Gibson, W. M.; and Rodgers, J. W.: Ion Bombardment Fabrication of Optical Waveguides Using Electron Resist Masks. Appl. Phys. Letters, vol. 21, 1972, p. 72.
19. Taylor, H. F.; Martin, W. E.; Hall, D. B.; and Smiley, V. N.: Fabrication of Single-Crystal Semiconductor Optical Waveguides by Solid-State Diffusion. Appl. Phys. Letters, vol. 21, 1972, p. 95.
20. Garmire, E.; Stoll, H.; and Yariv, A.: Optical Waveguiding in Proton-Implanted GaAs. Appl. Phys. Letters, vol. 21, 1972, p. 87.
21. Ramaswamy, V.: Epitaxial Electro-Optic Mixed-Crystal $(\text{NH}_4)_x\text{K}_{1-x}\text{H}_2\text{PO}_4$ Film Waveguide. Appl. Phys. Letters, vol. 21, 1972, p. 183.
22. Tien, P. K.; Martin, R. J.; Blank, S. L.; Wemple, S. H.; and Varnerin, L. J.: Optical Waveguides of Single-Crystal Garnet Films. Appl. Phys. Letters, vol. 21, 1972, p. 207.
23. Cho, A. Y. and Reinhart, F. K.: Growth of Three-Dimensional Dielectric Waveguides for Integrated Optics by Molecular-Beam-Epitaxy Method. Appl. Phys. Letters, vol. 21, 1972, p. 355.
24. Sosnowski, T. P. and Weber, H. P.: Thin Birefringent Polymer Films for Integrated Optics. Appl. Phys. Letters, vol. 21, 1972, p. 310.
25. Hammer, J. M.; Channin, D. J.; Duffy, M. T.; and Wittke, J. P.: Low-Loss Epitaxial ZnO Optical Waveguides. Appl. Phys. Letters, vol. 21, 1972, p. 358.
26. Rand, M. J. and Standley, R. D.: Silicon Oxynitride Films on Fused Silica for Optical Waveguides. Appl. Opt., vol. 11, 1972, p. 2482.
27. McFee, J. H.; McGee, J. D.; Chang, T. Y.; and Nguyen, V. T.: Guided-Wave Propagation at 10.6 μ m in Silver Bromide Thin Films. Appl. Phys. Letters, vol. 21, 1972, p. 534.
28. Izawa, T. and Nakagome, H.: Optical Waveguide Formed by Electrically Induced Migration of Ions in Glass Plates. Appl. Phys. Letters, vol. 21, 1972, p. 584.

29. Wei, D. T. Y.; Lee, W. W.; and Bloom, L. R.: Quartz Optical Waveguide by Ion Implantation. *Appl. Phys. Letters*, vol. 22, 1973, p. 5.
30. Cheo, P. K; Berak, J. M.; Oshinsky, W.; and Stindal, J. L.: Optical Waveguide Structures for CO₂ Lasers. *Appl. Opt.*, vol. 12, 1973, p. 500.
31. Goell, J. E.: Barium Silicate Films for Integrated Optical Circuits. *Appl. Opt.*, vol. 12, 1973, p. 737.
32. Kaminow, I. P. and Carruthers, J. R.: Optical Waveguiding Layers in LiNbO₃ and LiTaO₃. *Appl. Phys. Letters*, vol. 22, 1973, p. 526.
33. Tangonan, G.; Pastor, A. C.; and Pastor, R. C.: Single Crystal KCl Fibers for 10.6- μ m Integrated Optics. *Appl. Opt.*, vol. 12, 1973, p. 1110.
34. Ramaswamy, V. and Weber, H. P.: Low-Loss Polymer Films With Adjustable Refractive Index. *Appl. Opt.*, vol. 12, 1973, p. 1581.
35. Miyazawa, S.: Growth of LiNbO₃ Single-Crystal Film for Optical Waveguides. *Appl. Phys. Letters*, vol. 23, 1973, p. 198.

Optical Waveguides

1. Kane, J. and Osterberg, H.: Optical Characteristics of Planar Guided Modes. *J. Opt. Soc. Am.*, vol. 54, 1964, p. 347.
2. Osterberg, H. and Smith, L. W.: Transmission of Optical Energy Along Surfaces: Part I, Homogeneous Media. *J. Opt. Soc. Am.*, vol. 54, 1964, p. 1073.
3. Nelson, D. F. and McKenna, J.: Electromagnetic Modes of Anisotropic Dielectric Waveguides at p-n Junctions. *J. Appl. Phys.*, vol. 38, 1967, p. 4057.
4. Lotsch, H. K. V.: Physical-Optics Theory of Planar Dielectric Waveguides. *Optik*, vol. 27, 1968, p. 239.
5. Marcatili, E. A. J.: Dielectric Rectangular Waveguide and Directional Coupler for Integrated Optics. *Bell System Tech. J.*, vol. 48, 1969, p. 2071.

6. Marcatili, E. A. J.: Bends in Optical Dielectric Guides. *Bell System Tech. J.*, vol. 48, 1969, p. 2103
7. Takano, T. and Hamasaki, J.: Propagating Modes of a Metal-Clad-Dielectric-Slab Waveguide for Integrated Optics. *IEEE J. Quan. Elec.*, vol. QE-8, 1972, p. 206.
8. Wang, S.; Shah, M.; and Crow, J. D.: Studies of the Use of Gyrotropic and Anisotropic Materials for Mode Conversion in Thin-Film Optical-Waveguide Applications. *J. Appl. Phys.*, vol. 43, 1972, p. 1861.
9. Yamamoto, S.; Koyamada, Y.; and Makimoto, T.: Normal-Mode Analysis of Anisotropic and Gyrotropic Thin-Film Waveguides for Integrated Optics. *J. Appl. Phys.*, vol. 43, 1972, p. 5090.
10. Russo, D. P. G. and Harris, J. H.: Wave Propagation in Anisotropic Thin-Film Optical Waveguides. *J. Opt. Soc. Am.*, vol. 63, 1973, p. 133.
11. Ulrich, R. and Tacke, M.: Submillimeter Waveguiding on Periodic Metal Structure. *Appl. Phys. Letters*, vol. 22, 1973, p. 251.
12. Goell, J. E.: Electron-Resist Fabrication of Bends and Couplers for Integrated Optical Circuits. *Appl. Opt.*, vol. 12, 1973, p. 729.
13. Lit, J. W. Y. and Van Rooy, D. L.: Hybrid Lens Beam Waveguide. *Appl. Opt.*, vol. 12, 1973, p. 749.
14. Giallorenzi, T. G.; West, E. J.; Kirk, R.; Linther, R.; and Andrews, R. A.: Optical Waveguides Formed by Thermal Migration of Ions in Glass. *Appl. Opt.*, vol. 12, 1973, p. 1240.
15. Tien, P. K.; Martin, R. J.; and Smolinsky, G.: Formation of Light-Guiding Interconnections in an Integrated Optical Circuit by Composite Tapered-Film Coupling. *Appl. Opt.*, vol. 12, 1973, p. 1909.
16. Shank, C. V. and Schmidt, R. V.: Optical Technique for Producing $0.1\text{-}\mu$ Periodic Surface Structures. *Appl. Phys. Letters*, vol. 23, 1973, p. 154.

Optical Modes

1. Shubert, R. and Harris, J. H.: Optical Surface Waves on Thin Films and Their Application to Integrated Data Processors. IEEE Trans. Micro. Theory Tech., vol. MTT-16, 1968, p. 1048.
2. Marcuse, D. and Derosier, R. M.: Mode Conversion Caused by Diameter Changes of a Round Dielectric Waveguide. Bell System Tech. J., vol. 48, 1969, p. 3217.
3. Marcuse, D.: Mode Conversion Caused by Surface Imperfections of a Dielectric Slab Waveguide. Bell System Tech. J., vol. 48, 1969, p. 3187.
4. Tien, P. K.; Ulrich, R.; and Martin, R. J.: Modes of Propagating Light Waves in Thin Deposited Semiconductor Films. Appl. Phys. Letters, vol. 14, 1969, p. 291.
5. Wang, S.; Shah, M.; and Crow, J. D.: Wave Propagation in Thin-Film Optical Waveguide Using Gyrotropic and Anisotropic Materials as Substrates. IEEE J. Quan. Elec., vol. QE-7, 1971, p. 294.
6. Wang, S.; Shah, M. L.; and Crow, J. D.: Wave Propagation in Thin-Film Optical Waveguides Using Gyrotropic and Anisotropic Materials as Substrates. IEEE J. Quan. Elec., vol. QE-8, 1972, p. 212.
7. Shah, M.; Crow, J. D.; and Wang, S.: Optical-Waveguide Mode-Conversion Experiments. Appl. Phys. Letters, vol. 20, 1972, p. 66.
8. Suematsu, Y.; Hakuta, M.; Furuya, K.; Chiba, K.; and Hasumi, R.: Fundamental Transverse Electric Field (TE_0) Mode Selection for Thin-Film Asymmetric Light Guides. Appl. Phys. Letters, vol. 21, 1972, p. 291.
9. Yariv, A. and Armstrong, D. R.: Traveling Wave Oscillations in the Optical Region: A Theoretical Examination. J. Appl. Phys., vol. 44, 1973, p. 1600.

Optical Scattering and Losses

1. Marcuse, D.: Radiation Losses of Dielectric Waveguides in Terms of the Power Spectrum of the Wall Distortion Function. *Bell System Tech. J.*, vol. 48, 1969, p. 3233.
2. Snyder, A. W.: Excitation and Scattering of Modes on a Dielectric or Optical Fiber. *IEEE Trans. Micro. Theory Tech.*, vol. MIT-17, 1969, p. 1138.
3. Snyder, A. W.: Asymptotic Expressions for Eigenfunctions and Eigenvalues of a Dielectric or Optical Waveguide. *IEEE Trans. Micro. Theory Tech.*, vol. MIT-17, 1969, p. 1130.
4. Marcuse, D.: Radiation Losses of Tapered Dielectric Slab Waveguides. *Bell System Tech. J.*, vol. 49, 1970, p. 273.
5. Harris, J. H.; GiaRusso, D. P.; and Shubert, R.: Optical Waveguide Scattering and Griffith Microcracks. *Proc. IEEE Letters*, vol. 59, 1971, p. 1123.
6. Mea, G. D.; Drigo, A. V.; Mazzoldi, P.; Nardelli, G.; and Zannoni, R.: Disorder in Implanted Semiconductors: Energy Dependence and Penetration Depth. *Phys. Stat. Sol.*, vol. 4, 1971, p. 797.
7. Rawson, E. G.: Measurement of the Angular Distribution of Light Scattered from a Glass Fiber Optical Waveguide. *Appl. Opt.*, vol. 11, 1972, p. 2477.
8. Kato, D.: Fused-Silica-Core Glass Fiber as a Low-Loss Optical Waveguide. *Appl. Phys. Letters*, vol. 22, 1973, p. 3.
9. Kogelnik, H.; Shank, C. V.; and Bjorkholm, J. E.: Hybrid Scattering in Periodic Waveguides. *Appl. Phys. Letters*, vol. 22, 1973, p. 135.
10. Weber, H. P.; Dunn, F. A.; and Leibolt, W. N.: Loss Measurements in Thin-Film Optical Waveguides. *Appl. Opt.*, vol. 12, 1973, p. 755.
11. Burns, G.; Dacol, F.; Marinace, J. C.; Scott, B. A.; and Burstein, E.: Raman Scattering in Thin-Film Waveguides. *Appl. Phys. Letters*, vol. 22, 1973, p. 356.

12. Reisinger, A.: Characteristics of Optical Guided Modes in Lossy Waveguides. *Appl. Opt.*, vol. 12, 1973, p. 1015.

Optical Amplification

1. Snavely, B. B.: Flashlamp-Excited Organic Dye Lasers. *Proc. IEEE*, vol. 57, 1969, p. 1374.
2. Shank, C. V.; Dienes, A.; and Silfvast, W. T.: Single Pass Gain of Exciplex 4-MU and Rhodamine 6G Dye Laser Amplifiers. *Appl. Phys. Letters*, vol. 17, 1970, p. 307.
3. Tien, P. K.; Ulrich, R.; and Martin, R. J.: Optical Second Harmonic Generation in Form of Coherent Cerenkov Radiation from a Thin-Film Waveguide. *Appl. Phys. Letters*, vol. 17, 1970, p. 447.
4. Kogelnik, H. and Shank, C. V.: Stimulated Emission in a Periodic Structure. *Appl. Phys. Letters*, vol. 18, 1971, p. 152.
5. Ippen, E. P.; Shank, C. V.; and Dienes, A.: Rapid Photobleaching of Organic Laser Dyes in Continuously Operated Devices. *IEEE J. Quan. Elec.*, vol. QE-7, 1971, p. 178.
6. Kaminow, I. P.; Weber, H. P.; and Chandross, E. A.: Poly (Methyl Methacrylate) Dye Laser with Internal Diffraction Grating Resonator. *Appl. Phys. Letters*, vol. 18, 1971, p. 497.
7. Shaklee, K. L. and Leheny, R. F.: Direct Determination of Optical Gain in Semiconductor Crystals. *Appl. Phys. Letters*, vol. 18, 1971, p. 475.
8. Weber, H. P. and Ulrich, R.: A Thin-Film Ring Laser. *Appl. Phys. Letters*, vol. 19, 1971, p. 38.
9. Taylor, H. F.; Smiley, V. N.; Martin, W. E.; and Pawka, S. S.: Fluorescence of Graded-Band-Gap $\text{CdS}_x\text{Se}_{1-x}$ Crystals Produced by Diffusion. *Phys. Rev. B*, vol. 5, 1972, p. 1467.
10. Chang, M. S.; Burlamacchi, P.; Hu, C.; and Whinnery, J. R.: Light Amplification in a Thin Film. *Appl. Phys. Letters*, vol. 20, 1972, p. 313.

11. Zory, P.: Light Oscillation in Leaky Corrugated Optical Waveguides. Appl. Phys. Letters, vol. 22, 1973, p. 125.
12. Bjorkholm, J. E.; Sosnowski, T. P.; and Shank, C. V.: Distributed-Feedback Lasers in Optical Waveguides Deposited on Anisotropic Substrates. Appl. Phys. Letters, vol. 22, 1973, p. 132.
13. Wang, S.: Proposal of Periodic Layered Waveguide Structures for Distributed Lasers. J. Appl. Phys., vol. 44, 1973, p. 767.

REFERENCES

1. Physics Survey Committee, National Research Council: **Physics in Perspective, Vol I.** National Academy of Sciences, Washington, D. C., 1972.
2. Tien, P. K.: **Light Waves in Thin Films and Integrated Optics.** *Appl. Opt.*, vol. 10, 1971, p. 2395.
3. Miller, S. E.: **Integrated Optics: An Introduction.** *Bell System Tech. J.*, vol. 48, 1968, p. 2059.
4. Nelson, D. F. and Reinhart, F. K.: **Light Modulation by the Electro-Optic Effect in Reverse-Biased GaP P-N Junctions.** *Appl. Phys. Letters*, vol. 5, 1964, p. 148.
5. Kazarinov, R. F.; Konstantinov, O. V.; Perel, V. I.; and Efros, A. L.: **Electromagnetic Theory of the Injection Laser.** *Soviet Phys.-Solid State*, vol. 7, 1965, p. 1210.
6. Nelson, D. F. and McKenna, J.: **Electromagnetic Modes of Anisotropic Dielectric Waveguides at p-n Junctions.** *J. Appl. Phys.*, vol. 38, 1967, p. 4057.
7. Ashkin, A. and Gershenzon, M.: **Reflection and Guiding of Light at Small p-n Junctions.** *J. Appl. Phys.*, vol. 34, 1963, p. 2116.
8. Schineller, E. R.: **Single-Mode-Guide Laser Components.** *Microwaves*, vol. 7, 1968, p. 77.
9. Shubert, R. and Harris, J. H.: **Optical Surface Waves on Thin Films and Their Application to Integrated Data Processors.** *IEEE Trans. Micro. Theory Tech.*, vol. MTT-16, 1968, p. 1048.
10. Tien, P. K.; Ulrich, R.; and Martin, R. J.: **Modes of Propagating Light Waves in Thin Deposited Semiconductor Films.** *Appl. Phys. Letters*, vol. 14, 1969, p. 291.
11. Leurgans, P. and Turner, A. F.: **Frustrated Total Reflection Interference Filters.** *J. Opt. Soc. Am.*, vol. 37, 1947, p. 983.

REFERENCES (Continued)

12. Ulrich, R.: Optimum Excitation of Optical Surface Waves. *J. Opt. Soc. Am.*, vol. 61, 1971, p. 1467.
13. Tien, P. K.; Smolinsky, G.; and Martin, R. J.: Thin Organosilicon Films for Integrated Optics. *Appl. Opt.*, vol. 11, 1972, p. 637.
14. Dakss, M. L.; Kuhn, L.; Heidrich, P. F.; and Scott, B. A.: Grating Coupler for Efficient Excitation of Optical Guided Waves in Thin Films. *Appl. Phys. Letters*, vol. 16, 1970, p. 523.
15. Ostrowsky, D. B. and Jacques, A.: Formation of Optical Waveguides in Photoresist Films. *Appl. Phys. Letters*, vol. 18, 1971, p. 556.
16. Weber, H. W.; Ulrich, R.; Chandross, E. A.; and Tomlinson, W. J.: Light-Guiding Structures of Photoresist Films. *Appl. Phys. Letters*, vol. 20, 1972, p. 143.
17. Tien, P. K. and Martin, R. J.: Experiments on Light Waves in a Thin Tapered Film and a New Light-Wave Coupler. *Appl. Phys. Letters*, vol. 18, 1971, p. 398.
18. Kuhn, L.; Dakss, M. L.; Heidrich, P. F.; and Scott, B. A.: Deflection of an Optical Guided Wave by a Surface Acoustic Wave. *Appl. Phys. Letters*, vol. 17, 1970, p. 265.
19. Kuhn, L.; Heidrich, P. F.; and Lean, E. G.: Optical Guided Wave Mode Conversion by Acoustic Surface Wave. *Appl. Phys. Letters*, vol. 19, 1971, p. 428.
20. Chang, W. S. C.: Acousto-Optical Deflections in Thin Films. *IEEE J. Quan. Elec.*, vol. QE-7, 1971, p. 167.
21. Polky, J. N. and Harris, J. H.: Interdigital Electro-Optic Thin-Film Modulator. *Appl. Phys. Letters*, vol. 21, 1972, p. 307.
22. Tien, P. K.; Martin, R. J.; Wolfe, R.; LeCraw, R. C.; and Blank, S. L.: Switching and Modulation of Light in Magneto-Optic Waveguides of Garnet Films. *Appl. Phys. Letters*, vol. 21, 1972, p. 394.

REFERENCES (Concluded)

23. Tien, P. K.; Martin, R. J.; Blank, S. L.; Wemple, S. H.; and Varnerin, L. J.: Optical Waveguides of Single-Crystal Garnet Films. *Appl. Phys. Letters*, vol. 21, 1972, p. 207.
24. Ulrich, R. and Martin, R. J.: Geometrical Optics in Thin Film Light Guides. *Appl. Opt.*, vol. 10, 1971, p. 2077.
25. Shubert, R. and Harris, J. H.: Optical Guided-Wave Focusing and Diffraction. *J. Opt. Soc. Am.*, vol. 61, 1971, p. 154.
26. Righini, G. C.; Russo, V.; Sattini, S.; and di Francia, G. T.: Thin Film Geodesic Lens. *Appl. Opt.*, vol. 11, 1972, p. 1442.
27. Wang, S.; Shah, M. L.; and Crow, J. D.: Wave Propagation in Thin-Film Optical Waveguides Using Gyrotropic and Anisotropic Materials as Substrates. *IEEE J. Quan. Elec.*, vol. QE-8, 1972, p. 212.

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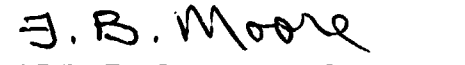
By Robert B. Owen

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